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The Equilibrium Moisture Content of Five Lesser Utilized Species of Ghana Contrasted with Three European Species

Gladys A. Quartey*, John Frank Eshun, Emmanual Yaw Wereko

Department of Interior Design Technology, Takoradi Technical University, Takoradi, Ghana
Email: *gladquartey@gmail.com

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Abstract

Equilibrium moisture contents (EMC) of wood species are very necessary in the utilization of these in service. This study investigated the EMC of five lesser utilized species of Ghana and compared it with that of three European species. Sixteen randomly sampled specimens of each of the eight species (heartwood and sapwood) with dimensions 3 cm × 3 cm × 3 cm were exposed at various relative humidity conditions of 30%, 45%, 60%, 75% and 90% in a temperature and humidity-controlled climate chamber at a temperature of 25˚C in accordance to German standard DIN 52182. The species are *Albies alba, Fagus sylvatica* and *Picea abies* which are European species and *Amphimas pterocarpoides*, *Antiaris toxicaria*, *Canarium schweinfurthii*, *Celtis zenkeri* and *Cola gigantea* are wood species from Ghana. Internal wood temperature and humidity were measured with datalogger. Samples were considered to have reached equilibrium at any given humidity when the daily weight changes were less than 0.1 mg according to German standard DIN 52183. After the last measurements of the weight changes, the samples were dried at 103˚C until there was a constant weight. The five tropical hardwoods had low sorption values recorded and high sorption values for the European species and this could be attributed to differences in the microstructure of these woods.

Keywords

Albies alba, *Fagus sylvatica*, *Picea abies*, Equilibrium Moisture Content, *Amphimas pterocarpoides*, *Antiaris toxicaria*, *Canarium schweinfurthii*, Lesser Utilized Hardwood Species

1. Introduction

Wood exposed to high humidity conditions or to liquid water during use may be subjected to biological deterioration. Skaar [1], quoting from Kirk and Cowling, Liquid water is needed in wood cells to provide a medium for diffusion of the enzymes or other metabolites by which wood-decomposing organisms digest the wood substance. If there is no liquid water present inside the wood cells, there will be no medium for diffusion, and therefore no biological decomposition except for certain insects of relatively minor importance. Thus, as long as wood is kept below its fiber-saturation point, it will never decay. Decay can be defined as the microbiological degradation of wood [2]. The damage of wood by fungi is essentially caused by the degradation of the cell wall by fungi, which decreases the mechanical wood properties and substantially reduces wood use [3]. In the tropical countries, the damage insects' cause to lumber and wood in service is of great economic loss. Although periodic estimates have been done for certain countries, the true worldwide losses in wood destroyed and labour expended in replacement cannot be evaluated with a satisfactory degree of accuracy, it is sufficient to state that the losses are extremely great, and measures taken by wood users to reduce such damage are a sound investment [4]. Moisture content clearly below fiber saturation point prevents or minimizes the attack by these organisms, particularly the decay fungi, because they need sufficient and easily available moisture to facilitate metabolism. Furthermore, the heartwood's lower rate of diffusion, the blocking of cell cavities by gums, resins, tyloses in the vessels and tylosoids in the resin canals adversely affect the balance between air and water necessary for the growth of fungi [4]. Therefore, the equilibrium moisture content of wood is very important.

Wood cellulose when exposed to an atmosphere of a constant temperature and humidity, ultimately attains a moisture content that remains constant so long as these conditions are altered. Freshly cut wood and wood which has been exposed to liquid water for a longer period have high moisture content (well above the fiber saturation point). Water bound to hygroscopic cell wall constituents and into voids of wood of radius less than 1.5 μm is called adsorbed water [5]. This critical point of sorption is called the fiber saturation point. It represents a water potential of −0.1 MPa and in theory, a relative humidity of 99.93% [6]. The water present in the cell lumens and intercellular space is called free or absorbed water [7]. At high moisture, the water can be found as free water, which is in the cell lumens, and as bound water, which is located within the cell wall material. As the wood begins to dry, when exposed to ambient air, moisture first leaves the wood from the lumens while the bound water remains constant. The moisture content level which corresponds to the lumens containing no free water (only water vapour), while no bound water has been desorbed from the cell wall material, is known as the fiber saturation point (FSP), normally in the range of 26% - 32% moisture content [8]. As the moisture content of wood decreases below the FSP the bound water will begin to leave the cell wall material. This is what is commonly known as desorption and the gain of bound water is known as adsorption/absorption. So, in essence water/moisture is lost or gained by the wood at any point in time. The rate of water/moisture loss depends on the amount of water already taken up and the temperature, while the rate of gaining depends on the number of absorbing (adsorbing) points in the material that is still unoccupied and on the concentration of water vapour in the surrounding atmosphere.

Timber is hygroscopic, that is it will absorb moisture from the atmosphere if it is dry and correspondingly yield moisture to the atmosphere when wet, thereby attaining moisture content which is in equilibrium with the water vapour pressure of the surrounding atmosphere. Thus, for any combination of vapour pressure and temperature of the atmosphere, there is corresponding moisture content of the timber such that no inward or outward diffusion of water vapour. This moisture content is referred to as the equilibrium moisture content (EMC) [9]. The EMC of wood in use is affected most dramatically by the relative humidity of the atmosphere to which it is exposed. According to Dinwoode [9], where timber is subjected to wide fluctuations in relative humidity, care must be exercised to select a species that has low movement values. Rydell [10] has done a study on the influence of the growth ring-width and density on properties which influences the durability of Swedish pine. One property that has been investigated is the absorption of water vapour from humid air. He concludes that the vapour absorption is slightly slower for specimens of higher density. On the other hand, the difference in moisture sorption of heart and sapwood is just as big as the influence of density.

In this study, the EMC of five lesser utilized species namely, *Amphimas pterocarpoides*, *Antiaris toxicaria*, *Canarium schweinfurthii*, *Celtis zenkeri*, *Cola gigantea* were compared with the EMC of three European species namely *Abies alba*, *Picea abies* and *Fagus sylvatica*.

2. Materials and Method

The Fenaso Nkwanta Forest which is 60 km south of Kumasi is a rich forest, near the gold mining town of Obuasi in the Ashanti Region of Ghana. Twenty fresh logs were felled and confirmed using the field guide to the forest trees of Ghana by Hawthorne [11] [12]. For each species, two trees of a diameter greater than 50 cm at breast height and lenghts of 15 m were felled. Each log was then cut into three pieces each of length 5 m. These were sawn into required lumber at Modern Wood Processing Factory in Kumasi and brought to the Wood Science workshop of the Faculty of Renewable Natural Resources where they were stacked and air dried for three months to a moisture content of about 15% - 35%. Between 10 - 16 beams were obtained for each of the eight timber species. The cross section of thickness of 40 mm was used to prepare samples for sorption tests.

Sixteen randomly sampled specimens of each of the seven species (heartwood and sapwood) with dimensions 3 cm × 3 cm × 3 cm were exposed at various relative humidity conditions of 30%, 45%, 60%, 75% and 90% in a temperature and humidity-controlled climate chamber (**Figure 1**) at a temperature of 25˚C

Figure 1. Climate chamber for the sorption experiment. Model: *Weiss* 500 *SB*; Temperature range: +10˚C to +95˚C; Humidity range: 15% to 98% R.H; Chamber dimension: 850 × 795 × 800 mm (B × D × H).

according to German standard [13]. In addition, *Albies alba, Fagus sylvatica* and *Picea abies* of the same dimensions were also added. Internal wood temperature and humidity were measured with datalogger. Samples were considered to have reached equilibrium at any given humidity when the daily weight changes were less than 0.1 mg according to German standard [14]. After the last measurements of the weight changes the samples were dried at 103˚C until there was a constant weight. The equilibrium moisture contents (EMC) were calculated on the basis of the oven-dried weight of the samples: The formula used was:

$$M = \frac{(w - w_o)}{w_o} \times 100\%$$

where w = mass of moist wood,

w_o = oven dry mass of wood,

M = moisture content of the wood.

3. Results and Discussion

Specimens of each of the eight species (heartwood and sapwood) were exposed at various relative humidity conditions of 30%, 45%, 60%, 75% and 90% in a temperature and humidity-controlled climate chamber at a temperature of 25˚C according to German standard [13]. The difference between the quantity of water after wetting in the sapwood and the heartwood was significant. The respective differences in the moisture content at the end of the adsorption test was nearly significant. The equilibrium moisture contents (EMC) of these wood species at the various relative humidity conditions with their standard deviations are presented in Table 1. According to Table 1, *Canarium schweinfurthii* sapwood had values from 3.9% to highest EMC of 20.9%. The sapwoods of *Amphimas*

Table 1. Equilibrium moisture contents of the five selected woods (x—average, s—standard deviation) at a Temperature of 25˚C under various relative humidity.

Species	Relative humidity:	30%	45%	60%	75%	90%
A. pterocarpoides	sapwood	3.7 (0.8)	5.7 (1.1)	7.0 (1.0)	11.3 (1.1)	19.1 (0.9)
	Heartwood	5.4 (0.1)	7.4 (0.2)	8.7 (0.1)	10.8 (0.2)	17.8 (0.2)
A. toxicaria	sapwood	5.4 (0.2)	7.7 (0.3)	9.0 (0.2)	12.2 (0.2)	19.2 (0.3)
	Heartwood	5.3 (0.2)	7.5 (0.2)	8.9 (0.2)	11.0 (0.2)	18.3 (0.3)
C. schweinfurthii	sapwood	3.9 (0.4)	7.4 (0.3)	8.6 (0.6)	12.7 (0.7)	20.9 (1.3)
	Heartwood	5.5 (0.7)	7.3 (0.3)	8.5 (0.4)	11.7 (0.7)	19.7 (1.3)
C. zenkeri	sapwood	5.2/ (0.3)	7.5 (0.3)	8.6 (0.2)	11.9 (0.2)	19.8 (0.2)
	Heartwood	4.8 (0.5)	7.0 (0.5)	8.2 (0.5)	11.4 (0.5)	17.6 (0.5)
C. gigantea	sapwood	5.4 (0.3)	7.7 (0.2)	9.1 (0.2)	11.5 (0.2)	18.4 (0.5)
	Heartwood	5.8 (0.2)	7.7 (0.1)	10.4 (0.7)	10.7 (0.1)	16.1 (0.5)

pterocarpoides had values from 3.7% to 19.1%*, Antiaris toxicaria* from 5.4% to 19.2%*, Celtis zenkeri* with values form 5.2% to 19.8%*. Cola gigantea had values from* 5.4% to 18.4%. The heartwoods of the above species had EMC values generally lower than the sapwood values ranging from 5.2% to 19.7% which is the highest for *C. Schweinfurthii*. The equilibrium moisture contents of the European species are also presented in **Table 2**. *Abies alba* had the highest EMC of 20.3% followed by values of 19.5% and 18.2% for *Fagus sylvatica* and *Picea abies* respectively.

At high humidity, sapwood was found to have a higher sorption than heartwood for most species. The low sorption of heartwood as against sapwood can be attributed to the bulking effect of the extractives and other inclusions in the heartwood which prevent water from being adsorbed. Skaar [8] discussed that the sorption isotherms of all woods were generally similar in shape. However, there may be considerable variations among them with respect to absolute values of hygroscopicity. This variation, he explained, may be because of differences in the proportion of primary wood constituents, such as cellulose, hemicelluloses, and lignin in different woods; or more importantly, because of differences in the kind and quantity of extractives. The hygroscopicity of woods with high extractive contents were generally lower than those without extractives. This was because according to Haygreen and Bowyer [15], these extractives occupy some sites in the cell wall that would otherwise attract water. *Amphimas pterocarpoides* was also another species whose sapwood had a high EMC value of 19.1% (**Table 1**) at 90% RH and this could be explained with the high cellulose value of 43.2% - 45.8% (**Table 3**) which provided more sites for the adsorption of water/moisture. Its heartwood because of the high extractive content of between 8.3% - 10.0% (**Table 3**) had a lowered EMC of 17.8 (**Table 1**). *Canarium schweinfurthii* sapwood also recorded a high EMC value of 20.9% at 90% RH (**Table 1**). This wood species has also been found to have high cellulose content ranging

Table 2. EMC of european species with standard deviations.

Species		30%	45%	60%	75%	90%
Abies alba	x (s)	8.1 (0.2)	10.2 (0.1)	11.6 (0.1)	13.5 (0.2)	20.3 (0.2)
Picea abies	x (s)	7.6 (0.2)	9.4 (0.2)	10.6 (0.2)	12.4 (0.2)	18.2 (0.3)
Fagus sylvatica	x (s)	7.5 (0.2)	10.0 (0.2)	11.3 (0.2)	13.0 (0.0)	19.5 (0.4)

Table 3. Chemical composition of some of the wood species studied.

Wood species	Cellulose	Hemicellulose	Lignin	Extractives
	%	%	%	%
Antiaris toxicaria	39.3 - 43.5	30.5 - 33.7	20.5 - 22.7	6.2 - 8.4
Amphimas pterocarpoides	43.2 - 45.8	27.8 - 31.9	23.8 - 28.5	8.3 - 10.0
Canarium schweinfurthii	42.2 - 45.6	30.4 - 34.5	21.7 - 25.9	8.4 - 9.2

Source: By courtesy of chemistry department of forest research institute of Ghana, Kumasi.

from 42.2 - 45.6 (**Table 3**) which may account for the high value recorded. The heartwood of *Canarium schweinfurthii* however recorded slightly lower EMC value of 19.7%. Kinnimonth [16] concluded that drying at high temperatures reduces equilibrium moisture contents compared with those of air-dried wood when it was subsequently exposed to changing conditions of humidity. Brazier [17] emphasized that it was the maintenance of stability which was particularly important as more demanding performance requirements were sought from timber, particularly for furniture and joinery uses, as well as in other building uses.

The generally low values of sorption recorded for the five species as shown in **Table 1** and the high values of sorption for the European species in **Table 2** could be attributed to differences in the microstructure of these woods. According to Dinwoode [9], European hardwoods like *Fagus sylvatica* were known to have lower extractive contents than tropical hardwoods whilst softwoods like *Abies alba* and *Picea abies* have even lower extractive contents. Out of the three species *Fagus sylvatica*, a hardwood, was supposed to have a lower EMC value than *Picea abies*, a softwood, but this was not the case because according to Fengel and Wegener [18], *Fagus sylvatica* had high amount of polar extractives which even though occupy sites where water cannot occupy tend to attract water/moisture and dissolve in it thereby explaining the slightly higher EMC value of 19.5% at 90% RH of *Fagus sylvatica* than for *Picea abies.* Another reason why the EMC values for the European species were higher than the tropical wood species was density. All the European species used had densities ranging from 0.41 - 0.68 g/cm^3 whilst the tropical wood species had densities ranging from 0.44 - 1.0 g/cm^3. Denser wood species also have slower absorption of vapour than lighter woods (**Table 4** and **Figure 2**). This agreed with Rydell [10] when he concluded that vapour absorption was slightly slower for specimens of higher density.

Table 4. Densities and EMC at 90% relative humidity of the eight species.

A. pterocarpoides	19.1	770
A. toxicaria	19.2	440
C. schwienfurthii	20.9	490
C. zenkeri	19.8	650
C. gigantea	18.4	670
A. alba	20.3	450
P. abies	18.2	560
F. sylvatica	19.5	750

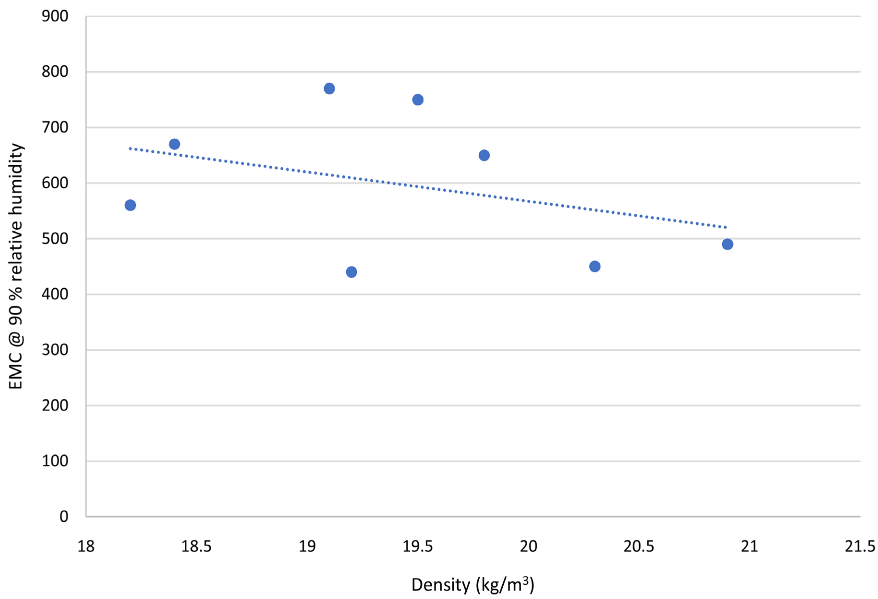

Figure 2. Water sorption and density of the eight timber species studied.

It was well known that the risk of fungal attack on lignocelluloses was very high if the water content reaches 20% at temperature of about 20˚C [19]. All the samples used in this study, were attacked by fungi at the climate condition of 90% RH and temperature of 25˚C.

4. Conclusion

These species are lesser utilized and of abundance occurrence. If their equilibrium moisture contents are known it will help designers and woodworkers to not use them in areas where they will come into contact with moisture but to as much as possible protect them when using them outdoors. Hygroscopicity is of primary importance because moisture in wood affects all wood properties. For example, moisture content can increase the weight of wood by hundred percent or more, with consequential effects on transportation costs. Variation in moisture content causes wood to shrink or swell, altering its dimensions. The ability to resist decay and insects is greatly affected by how much moisture is in the wood. The processing of wood from cutting, planing, gluing, and finishing of wood as well as its stength, reaction to heat, and acoustic properties are all affected by moisture content. Other processing activities, such as drying, preservative treatment, and pulping are also affected. Excessive moisture content causes dimensional problems when the wood is in service. The best solution is the wood in service to have a moisture content at the approximate midpoint of the expected range of moisture content of the environment in a particular location. This way moisture content fluctuations are minimised, thereby, minimising the effects associated with such fluctuations such as shrinkage and swelling of the wood. Generally, there is an inverse relationship between moisture content and the strength properties of wood that is a decrease in moisture content is accompanied by an increase in most strength properties and *vice versa*.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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